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Effect of temperature on mechanical properties and creep responses for wood/PVC composites

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HIGHLIGHTS

- We presented effect of temperature on mechanical properties and creep responses of Wood/PVC composites.
- We provided empirical equation representing mechanical properties as a function of temperature.
- The creep models combining time–stress and time–stress–temperature dependencies were obtained.
- Good correlations between analytical models and experimental results were obtained.

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ABSTRACT

This work presents the effect of temperature on mechanical properties and tensile creep responses of Wood/PVC (WPVC) composite materials. The materials were produced by an industrial scale twin crew extruder using the weight ratio of wood and PVC compound of 1:1. The tensile, compressive, and flexural properties were determined at various temperatures (25 °C, 40 °C, 50 °C, 60 °C, and 70 °C). The tensile creep responses and creep models at these temperatures were also included in this work. The experimental results indicate that mechanical strength of WPVC composites decreased significantly at temperature higher than 50 °C while the modulus of elasticity was affected significantly at temperature higher than 60 °C. The material properties at large deformation as mechanical strength was found to be more sensitive to the temperature change than the mechanical modulus at small deformation. The empirical equation representing mechanical properties as a function of temperature was also provided together with recommended adjustment factors for the design phase. The creep models combining time–stress dependencies using power form and time–stress–temperature dependencies using Pickel's form were obtained. Close agreement was observed representing adequacy of these models to predict the long-term deformation of the WPVC composites. This provided information would be useful for the design of WPVC composite member in structural and construction applications.

1. Introduction

There is a significantly increasing demand for using Wood/Poly Vinyl Chloride (WPVC) composite materials in many new applications including using them as construction material in civil engineering projects [1]. The advantages of the WPVC composite material are light weight, low water absorption, termite resistance, humidity resistance, environment erosion resistance, dimensional stability, and low maintenance requirement. Our previous works [2,3] have indicated that WPVC composites are anisotropic and non-homogeneous and also have lower mechanical properties than natural wood. We have also found that creep response and relative creep of the WPVC composites are higher than natural wood [2,3]. As we know that creep response is very important, one more work of authors [4] presented the computational investigation on the flexural creep response of WPVC composites using finite element software of ABAQUS. The plot of displacement versus time of WPVC composite members under various sustained loads were presented and verified with those of experimental results. The

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power law creep model which typically used to produce the empirical equation of creep responses of wood plastic composites [5–12] and plastics [13] was used for this research.

According to creep behavior of WPVC composites, previous works [2–4] reported only the flexural creep responses of the WPVC composites. However, time-dependent behaviors as creep responses of WPVC composites have been very important, especially, for using WPVC composites as structural member or construction materials. From this point of view, creep models are required in order to predict the long-term deformation of construction material. Therefore, this work continues along this line of research where here we investigate the tensile creep response of WPVC composites. Wood/PVC (WPVC) composites are basically extruded as large hollowed products whose consist of web, top flange, and bottom flanges. During the application of bending load, the top or bottom flanges of the WPVC composite member experience either tension force or compression force, depending on the boundary conditions. Based on our previous works [4,20], the tension resistance of the WPVC composite member was more critical (weaker) than the compression and some previous researches [14–16] also focused on the tensile creep response of wood with other plastics. Therefore, the tensile creep response is very essential to explore and thus, has become of our main interest in this present work. In case of temperature effect, previous works [5–12] have suggested that higher temperature can significantly affect mechanical properties (e.g., modulus of rupture and modulus of elasticity) and creep response of the materials. However, few studies have investigated the effect of temperature on the mechanical properties and creep responses of WPVC composites. Such an investigation is normally performed in case of wood with other plastics [5–12] and natural wood [17,18]. Therefore, beside the investigation on the tensile creep response (mentioned above), this work also aims to present the effect of temperature on the mechanical properties and creep responses of WPVC composites. We believe that our results not only give a comprehensive understanding of the effect of temperature on mechanical properties and creep responses for wood/PVC composites, but also would interest engineers and scientists who use the WPVC composites as construction material and structural members.

2. Experimental

2.1. WPVC composite materials

The polymer matrix used in this work was suspension poly (vinyl chloride) (PVC) powder with a *K* value of 66, provided by V.P. Wood Co., Ltd. (Bangkok Thailand). The PVC powder was initially dry-blended with various necessary additives to give PVC compound before melt-blending with wood particles in making wood/PVC composites (WPVC). Based on our previous work [19], *N-2* (aminoethyl) 3-aminopropyl trimethoxysilane (KBM603, $M_w = 222.4$) was most suitable for WPVC. Therefore, it was used here together with the other additives [in parts per hundred (pph) of PVC] including a PVC organic complex stabilizer (TS-DBL-Pb-Ba, 3.6 pph), an external lubricant (Finalux G-741, 0.6 pph), calcium carbonate (Omyacarb-2T, 9 pph), calcium stearate (0.3 pph), and acrylic-based processing aids (PA20, 8 pph). The wood particles, provided by V.P. Wood Co., Ltd. (Bangkok Thailand), had an average size of 100–300 μm. In this work, the content of the wood particles in the PVC compounds was fixed at 100 (in part per hundred (pph) of PVC powder), or wood particles 100 parts in 100 parts of PVC powder by weight. The wood particles were chemically treated with 1.0 wt% KBM 603 coupling agent.

2.2. Preparation of WPVC composite specimens

An industrial-scale twin-screw extruder with counter-rotating screws (KMD-90-36, KraussMaffei Technologies GmbH, Germany) was used for preparation of WPVC composites. The melt blending and sample preparation processes were commenced by (i) drying the KBM603 treated wood particles in hot oven with temperature of 80 °C, (ii) dry-blending the PVC compound with the dried wood particles using a high speed mixer, (iii) melt-blending in the twin-screw extruder with the blending temperature of 180 °C, (iv) extruding the molten WPVC composites through the die, and (v) passing through a cooling-system for composites solidification. The solidified WPVC composite member had four hollow cores with body dimensions of 38 × 144 mm^2. The thicknesses of top and bottom flanges were 6 mm while the web thickness was 6 mm [20]. This WPVC composite member has been industrial commercialized with a large quantity of fabrication. The consistencies in dimensions and properties were accepted with the customer.

3. Characterizations

3.1. Mechanical properties at different temperatures

Mechanical properties obtained from tensile, compressive, and flexural tests of WPVC composites were determined at different temperatures. The tensile test was carried out in accordance with ASTM D638 [21]. Tested specimens were cut and shaped as specimens specified in ASTM except the thickness of specimens. The original thickness from commercial WPVC composite section was used. In case of compressive test, the tested specimens were cut from commercial hollow section and carried out the tested method in accordance with ASTM D6108 [22]. The flexural test was carried out in accordance with ASTM D790 [23] where the tested specimens were cut and shaped as rectangular specimens using original thickness. The testing temperatures used in this study were room temperature (25 °C), 40 °C, 50 °C, 60 °C, and 70 °C, respectively. For all mechanical properties, at least three specimens per temperature were determined to obtain the stress–strain relationship, mechanical strength, and modulus of elasticity. The Instron universal testing machine (model ID of 5969S1121 with capacity of 50 kN) with the built-in oven (model ID of 3119-506 and serial number of 0005860) was used for this study.

3.2. Short term tensile creep test at different temperatures

The tensile creep test of WPVC composites was carried out in accordance with ASTM D638 [21]. Three independent specimens were tested using the Instron universal testing machine (Model ID of 5969S1121 with capacity of 50 kN) with the built-in oven (model ID of 3119-506 and serial number of 0005860). The initial deformation of the tested specimens and additional deformations, as a function of time due to sustained applied loading, were then recorded. In this work, WPVC composite specimens were subjected to a sustained applied load for a period of 180 min and monitored the changes in deformation at every 0.1 s [8,10]. The first group of specimen was tested at various sustained applied loads of 25%, 40%, and 55% of ultimate loading while the applied temperature was fixed at 50 °C in order to determine the effect of applied sustained loads. For this group of specimens, creep models combining time–stress dependencies for specified temperatures can be determined. Another group of specimens was tested with a constant sustained applied load of 40% while the applied temperature was varied as room temperature (25 °C), 50 °C, and 70 °C in order to investigate the effect of temperatures on creep response of WPVC composites. Based on the two groups of designed experiments, the empirical equation of creep response (creep models) of WPVC composites combining time–temperature–stress dependencies can be determined.

4. Results and discussion

4.1. Mechanical properties of WPVC composites

Fig. 1 presents the changes in tensile stress–strain relationship of WPVC composites at different temperatures while Table 1 shows the tensile strength and tensile modulus of elasticity of WPVC composites as well as the differences of these mechanical properties between specified temperatures and room temperatures (RT at 25 °C). The obtained results indicate that tensile strength and tensile modulus of elasticity decreased with increasing temperature.